# Waves, Currents, & Bathymetric Evolution Near An Inlet

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## LONG-TERM GOALS

The long-term objective is to develop field-verified models for the wave fields, circulation patterns, and morphological evolution near inlets and river mouths.

## OBJECTIVES

The objectives of our studies in FY12 were to

- obtain observations of currents, waves, and bathymetry near New River Inlet, NC,
- place quality controlled data on the WWW for other team members use, and
- begin to develop, test, and improve models for nearshore processes near and within an inlet channel.

In addition to field work at New River Inlet, we continued analysis of our Skagit tidal flats measurements, investigated the behavior of crater-like holes in the swash zone, compared observations with numerical simulations of waves propagating across the shallow, muddy, Louisiana continental shelf, and began analysis (with David Clark) of estimates of surfzone vorticity and short-crested breaking waves.

## APPROACH

Our approach is to collect field observations to test existing hypotheses, to discover new phenomena, to provide ground truth for remote sensing studies, to initialize and test data assimilative models that invert for bathymetry, and to calibrate, evaluate, and improve models for inlet hydrodynamics and morphological evolution.

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## WORK COMPLETED

*i) Circulation on Tidal Flats*

The generation and destruction of stratification on the Skagit tidal flats was investigated as part of Vera Pavel's PhD thesis (defended successfully in June, 2012) (Pavel *et al.* 2012). We also investigated the spatial and temporal structure of winds on the tidal flats (Raubenheimer *et al.* 2012)

*ii) Wave propagation over muddy seafloors*

The effect of a muddy seafloor on wave dissipation and on fetch-limited wave generation was studied by comparing SWAN numerical wave-model predictions with observations (Engelstad *et al.* 2012).

*iii) Behavior of crater-like holes in the swash*

Man-made 10-m diameter, 2-m deep crater-like holes made with a backhoe near the low tide line on an ocean beach were monitored as they refilled with sediment (Elgar *et al.* 2012).

*iv) New River Inlet*

Waves and current sensors were deployed at 32 locations near New River Inlet from April 27 through June 1, 2012 (Figure1). The data have undergone initial quality control and have been placed on the WWW for use by other ONR team members and colleagues. Analysis of the data has begun.

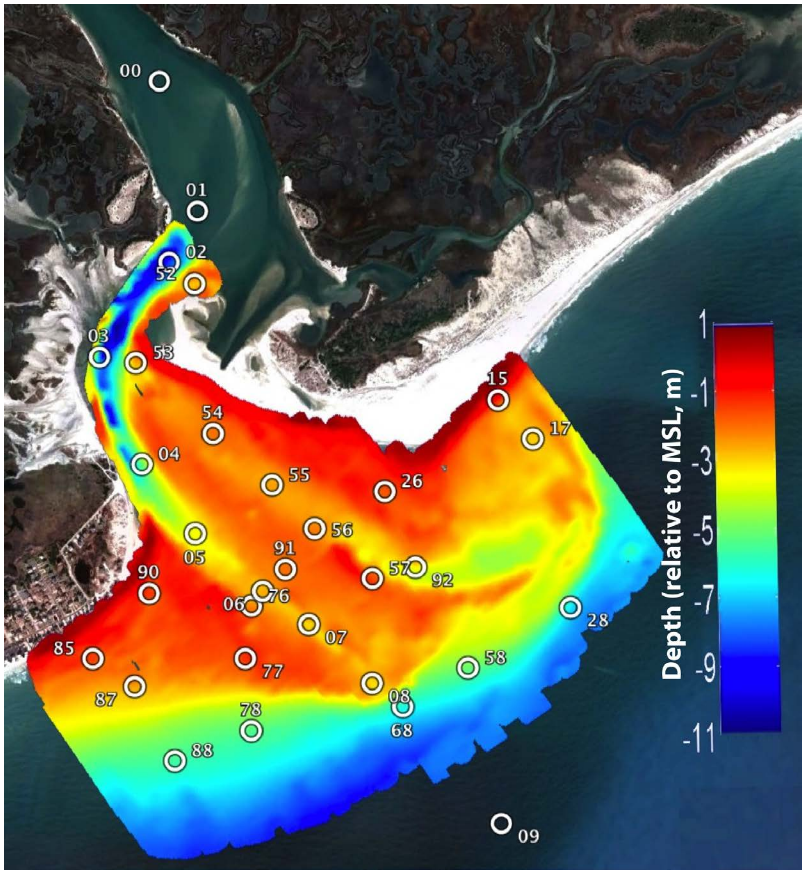


***Figure 1. Array of in situ wave and current sensors (white circles) deployed at New River Inlet, spring 2012. The color contours are water depth (Provided by J. McNinch). [Instruments are located across the ebb shoal and about 2 km up the inlet channel in depths from 1 to 10 m].***

## RESULTS

*i) Circulation and Morphological Change on Tidal Flats*

Stratification of the shallow waters on tidal flats is important because it affects turbulence, mixing, bottom stress, circulation, and sediment transport. The observations of density, currents, and sea levels collected in 2008 and 2009 on the shallow, broad, periodically inundated tidal flats (shoals) that lie between the mouths of the north and south forks of the Skagit River were used to investigate the processes driving the temporal and spatial variations of stratification.

The stratification on the tidal flats was generated primarily by tidal straining (owing to the vertically sheared velocity profile acting on the horizontal density gradient, figure 2, dashed purple), whereas mixing (figure 2, dashed green) was the primary mechanism destroying stratification (Pavel *et al*. 2012). Temporal changes in the stratification on the mid flats also resulted from advection (figure 2, solid blue curve) along and across the flats.

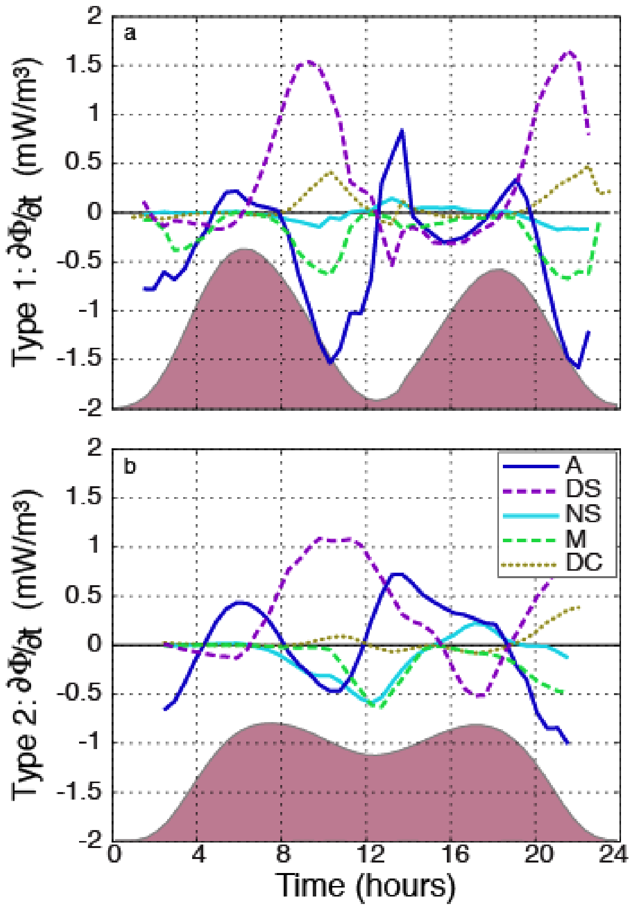


***Figure 2: Phase-averaged estimates of processes for (a) type 1 and (b) type 2 tides. The shaded area shows the relative water depth over a tidal cycle. The colored curves are advection (A, solid dark blue), depth-mean straining (DS, dashed purple), non-mean straining (NS, solid light blue), mixing (M, dashed green), and depth change (DC, dashed olive).***

*ii) Wave propagation over muddy seafloors*

Waves propagating across a shallow, muddy continental shelf undergo strong dissipation. The dissipative processes result in less generation of high frequency "sea" waves than predicted by models of waves over sandy seafloors. In some cases these models predict increasing wave energy owing to generation by wind, whereas the observations indicate decreasing energy, presumably owing to mud-induced dissipation (Englestad *et al.* 2012).

*iii) Behavior of crater-like holes in the swash*

Man-made crater-like holes dug near the low tide line rapidly refilled with sediment as the tide rose and swash flowed around and within the holes (figure 3). In collaboration with current (Melissa Moulton) and former (Jim Thomson) students, we showed that the water inside the evolving holes oscillated according to theory, with a half-wavelength mode when the hole was circular, and a quarter-wavelength mode when the hole was semi-circular (Elgar *et al.* 2012).

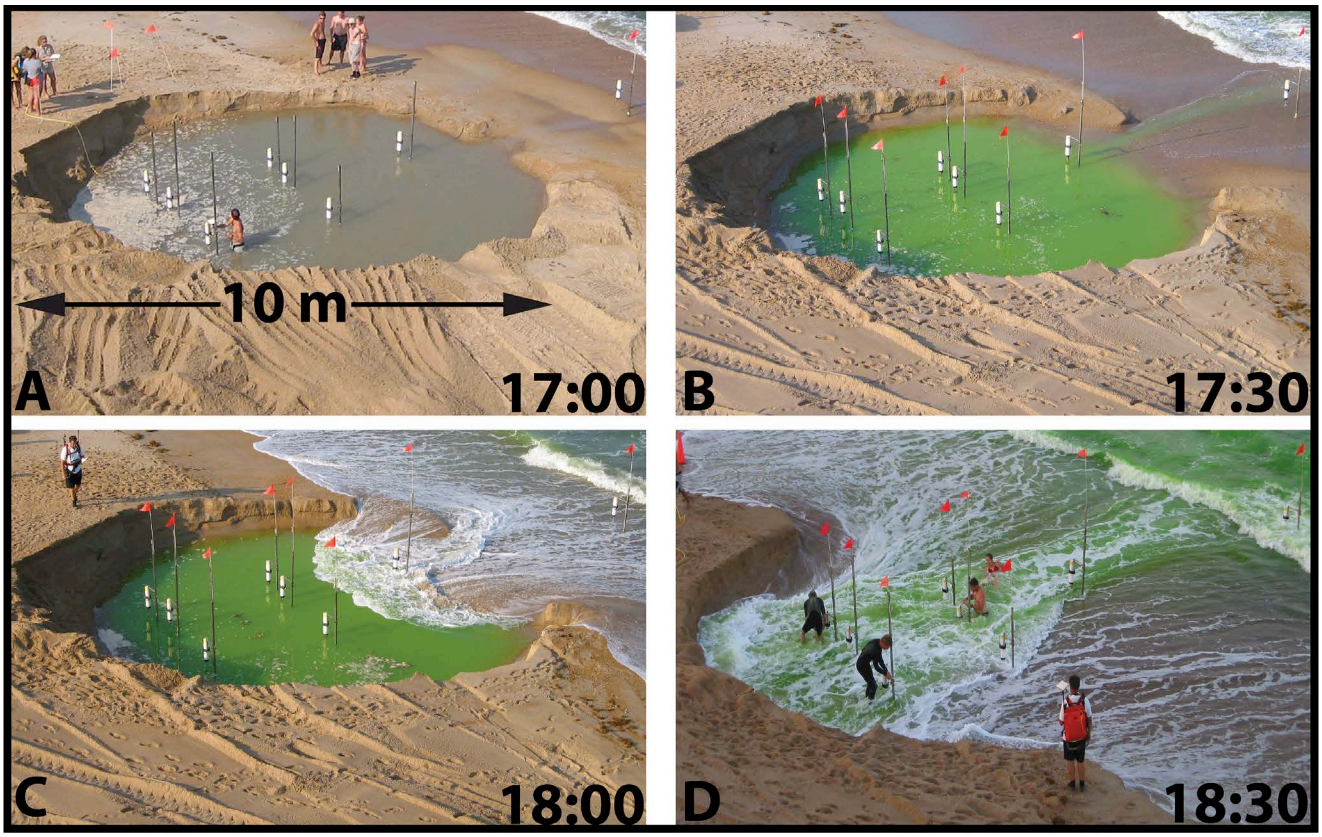


***Figure 3. Photographs of the man-made hole at different times (hours (EST) of Sep 19, 2005 are listed). White cylinders on vertical pipes are current meters. [An initially circular hole, 2 m deep, 10 m in diameter at 1700 hrs developed a small hole on the seaward side by 1730 hrs. The gap enlarged to twice its size by 1800 hours, and by 1830 hrs the initially circular hole had become semi-circular, open to the ocean.]***

*iv) New River Inlet*

Analysis of the field observations from New River (figure 1) began this summer. PhD student Julia Hopkins produced maps of mean flows for 846 one-hour data runs (figure 4) that show the strongest ebb currents occur near low tide. Flood flows are weaker than ebb flows, and occur at high tide. PhD student Anna Wargula has shown that offshore waves (figure 5 upper) affect the subtidal current fluctuations (red curve in figure 5 lower).

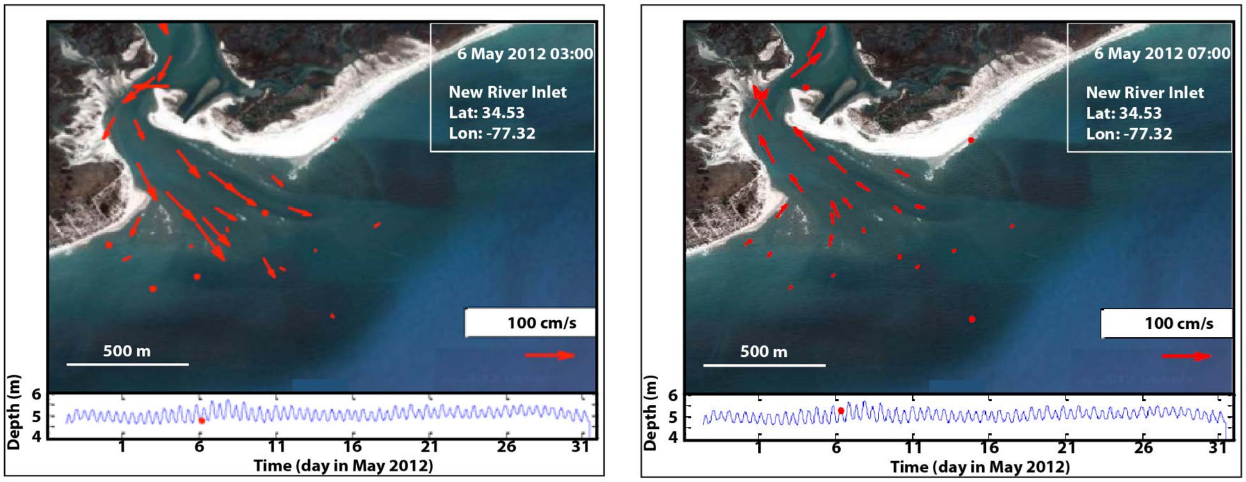


***Figure 4. Google Earth image of New River Inlet with 1-hr mean flow vectors (red arrows, scale on lower right) for (left) ebb and (right) flood flows. Below each panel is a time series of sea level (tidal height) observed in about 3 m depth. [The plots show up to 1.5 m/s ebb flows at low tide and flood flows at high tide.]***

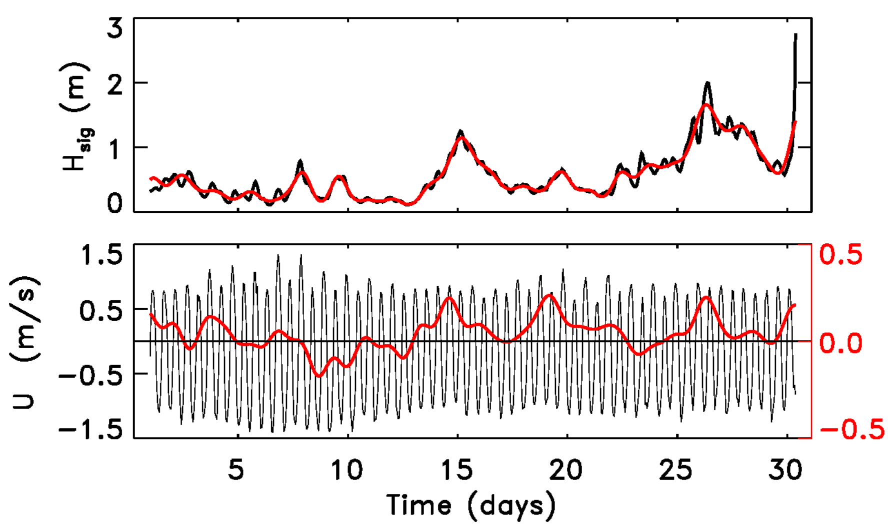


***Figure 5. (Upper) Significant wave height in 5-m water depth and (Lower) currents in the inlet channel mouth (approximately 5-m water depth) versus time for May 2012. Black curves are 1-hr means, red curves are demeaned and low-passed filtered (periods > 30 hrs) time series. [The wave heights usually are less than 1 m, but were 1.5, 2.0, and 2.8 m as tropical storms passed. The 1-hr mean currents vary between +/- 1.5 m/s with the 12-hr tide, and the low passed currents are correlated with the offshore waves.***

Anna also has shown that a cross-shore momentum balance holds between bottom stresses from the current in the inlet mouth and radiation stresses from waves propagating between the seaward edge of the ebb shoal and the inlet mouth (figure 6). Other processes (pressure gradients, wind stress, acceleration, nonlinear terms) are being investigated.

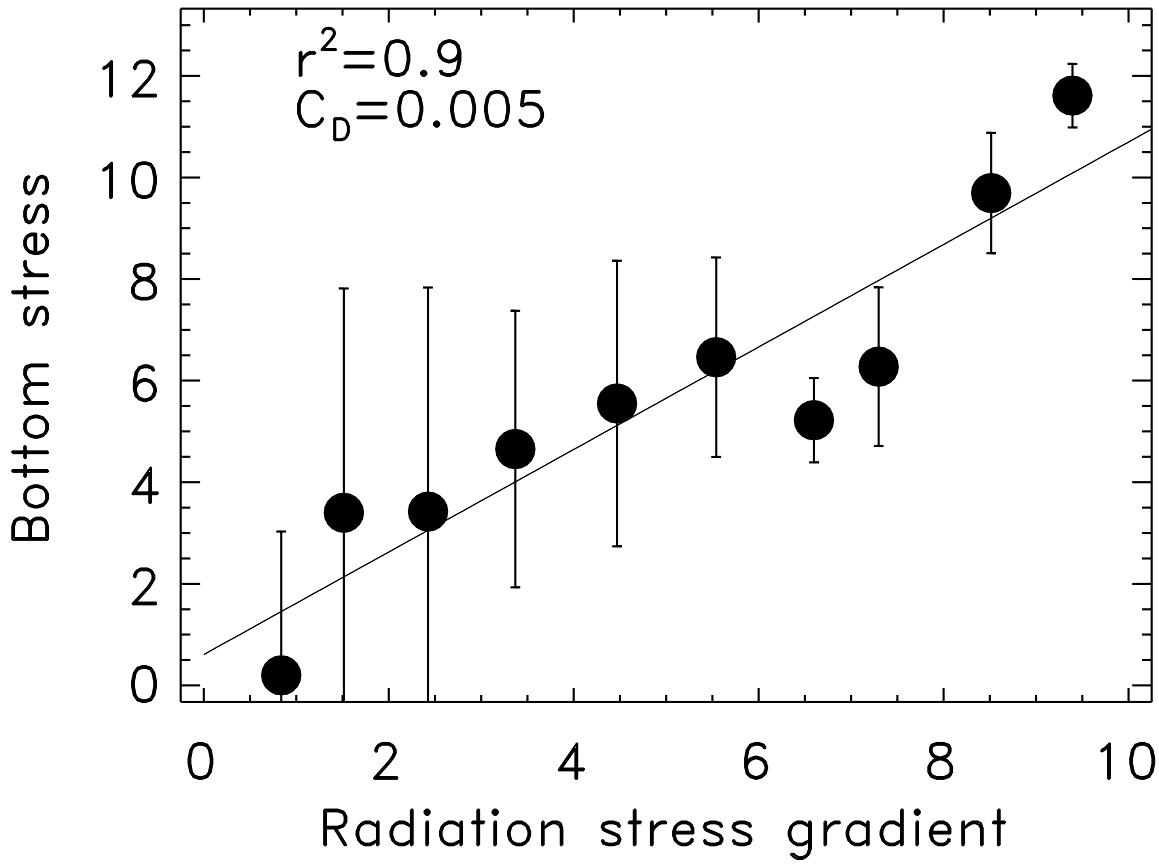


***Figure 6. Bottom stress (arbitrary units) versus radiation stress gradient (arbitrary units). The symbols are mean values of binned data and the bars are +/- 1 standard deviation within that bin. Bottom stress was estimated from observations of currents in the inlet mouth and radiation stress gradients were estimated from waves propagating between the seaward edge of the ebb shoal (5-m water depth) and the inlet mouth. The correlation ($r^2$) is 0.9 and the slope of the best-fit line (an approximation to the drag coefficient) is 0.005. [Binned values of bottom stress fall close to a line that increases with increasing radiation stress. Standard deviations are large, possibly owing to neglect of other terms in the momentum balance.]***

## IMPACT/APPLICATIONS

The Skagit Bay investigations imply that stratification is important even in the shallow waters of tidal flat shoals, and that advection, straining, and mixing dominate the generation and destruction of stratification.

Preliminary results from New River Inlet suggest that offshore waves can have a strong influence on currents and circulation near and within the inlet channel.

Field observations in a range of nearshore environments have been used to test and improve model predictions for waves, circulation, and morphological changes, as well as to provide ground truth for remote sensing of littoral areas and to initialize and test models that invert for the underlying bathymetry.

## RELATED PROJECTS

Our observations on the tidal flat are part of a larger effort to investigate and model physical, geological, and morphological processes on tidal flats. As part of the Tidal Flats DRI we have provided bathymetric surveys to all DRI team members, and ground truth (currents, water temperature, salinity) to colleagues conducting numerical model simulations and investigating remote sensing techniques.

The observations of mud-induced dissipation of surface-gravity waves are part of a study that includes colleagues from several other institutions. Our spatially dense observations of waves and currents were part of a larger array of wave sensors spanning many km of the continental shelf, and part of an array that included intensely instrumented tripods with sensors to measure the lutocline and mud properties.

The observations of waves and currents near New River Inlet are being used as ground truth for remote sensing studies (MURI colleagues), to test and improve models for wave propagation, circulation, and morphological evolution, and to initialize and test models that invert for the underlying bathymetry.

Many investigators are using our observational databases to test components of models (eg, the NOPP nearshore community model, DELFT3D, nonlinear wave propagation schemes) for nearshore waves, currents, and bathymetry, and as ground truth for remote sensing studies. More than 100 scientists, engineers, postdoctoral researchers, and students, have accessed our data distribution WWW site [http://science.whoi.edu/users/elgar/main.html] since 2006 to download time series and processed data products for their studies. In FY12 at least four journal papers used data we gathered in Duck, NC in 1994 (!), and more than 20 people (including investigators from U.S. and international universities, government and DoD laboratories, and private companies) downloaded data from the Duck94, SandyDuck, NCEX, SWASHX, WORMSEX, STIFEX, and RIVET1 projects.

Some of the work discussed here was in collaboration with Dr. Elgar's NSSEFF project to study morphological evolution in littoral areas.

## REFERENCES


Elgar, Steve, Britt Raubenheimer, Jim Thomson, and Melissa Moulton, 2012 Resonances in an evolving hole in the swash zone, *Journal Waterway, Port, Coastal, and Ocean Engineering,* **138**, 299-302, doi:10.1061/(ASCE)WW.1943-5460.0000136.

Englestad, Anita, T. Janssen, T.H.C. Herbers, G. van Vledder, Steve Elgar, Britt Raubenheimer, Lincoln Trainer, and Ana Garcia-Garcia, 2012 Wave evolution across the Louisiana shelf, *Continental Shelf Research, sub judice.*

Pavel, V., Britt Raubenheimer, and Steve Elgar, 2012 Processes controlling stratification on the northern Skagit Bay tidal flats, *Continental Shelf Research,* **in press.**

Raubenheimer, Britt, D. Ralston, Steve Elgar, D. Giffen, and R. Signell, 2012 Winds on the Skagit tidal flats, *Continental Shelf Research,* doi:10.1016/j.csr.2012.02.001.

## PUBLICATIONS

1. Raubenheimer, Britt, D. Ralston, Steve Elgar, D. Giffen, and R. Signell, 2012 Winds on the Skagit tidal flats, *Continental Shelf Research,* doi:10.1016/j.csr.2012.02.001. [published, refereed]

2. Elgar, Steve, Britt Raubenheimer, Jim Thomson, and Melissa Moulton, 2012 Resonances in an evolving hole in the swash zone, *Journal Waterway, Port, Coastal, and Ocean Engineering,* **138**, 299-302, doi:10.1061/(ASCE)WW.1943-5460.0000136 [Featured as an ASCE "Research Highlight."] [published, refereed]

3. Pavel, V., Britt Raubeneheimer, and Steve Elgar, 2012 Processes controlling stratification on the northern Skagit Bay tidal flats, *Continental Shelf Research,* **in press.** [in press, refereed]

4. Englestad, Anita, T. Janssen, T.H.C. Herbers, G. van Vledder, Steve Elgar, Britt Raubenheimer, Lincoln Trainer, and Ana Garcia-Garcia, 2012 Wave evolution across the Louisiana shelf, *Continental Shelf Research, sub judice.* [refereed]

5. Clark, D., Steve Elgar, and Britt Raubenheimer, 2012 Vorticity generation by short-crested waves, *GRL, sub judice*. [refereed]

## HONORS/AWARDS/PRIZES

The paper by Elgar, Raubenheimer, Thomson, and Moulton: **Resonances in an evolving hole in the swash zone**, *Journal Waterway, Port, Coastal, and Ocean Engineering,* **138**, 299-302, doi:10.1061/(ASCE)WW.1943-5460.0000136 was featured as an ASCE "Reasearch Highlight."

Dr. Elgar is a National Security Science and Engineering Faculty Fellow for the Office of the Secretary of Defense (the only earth scientist of the 29 fellows).